論 文 の 内 容 の 要 旨

論文題目

Fully Nonlinear Finite Element Model for Dynamic Response Analysis of Floating Offshore Wind Turbine System

浮体式洋上風力発電システム動的応答予測のための非線形 FEM モデルの開発

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Most of world's metropolises are near shore and offshore wind energy offers the obvious advantages of no land usage and a more reliable wind resource. In Japan, the offshore consist of a vast wind resource in deep water where use of conventional bottom-mounted wind turbines is not possible. Thus, it is essential to develop a tool for proper design of floating offshore wind turbine system to make offshore energy reliable and economically feasible.

In the current study, a fully nonlinear finite element model has been developed for dynamic response prediction of floating offshore wind turbine systems, considering coupling of wind turbine, floater and mooring system. A water tank experiment is performed using floater with different heave plate sizes to verify the performance of the developed model. The model is used to investigate the influence of heave plates and mooring system on floater response. The influence of floater motion on wind turbine loads is investigated using catenary and tension-legged mooring types.

Chapter 1 is a review of current situation of offshore energy around the world and in Japan. It explains why it is essential to use floating wind turbine systems in Japan. The outline of this dissertation is also presented.

In Chapter 2, the floating wind turbine technology is reviewed. A survey of the previous research in floating wind turbine technology is carried out and based on its conclusions and limitations, objectives of this research are presented.

In Chapter 3, experiments performed for the verification of the developed model are outlined. A water tank experiment has been carried out on an original floater and its two modifications with different heave plate sizes to investigate their influence on floater response and increase database for validation of the developed model. An experiment on a catenary chain is also performed to verify the performance of contact model for seabed interaction.

Chapter 4 gives detail of the numerical model and its validation through comparison with experiments explained in previous chapter. The model use Morison equation with Srinivasan's model for hydrodynamic force. The model employs a proposed non-hydrostatic method for restoring force. The model can consider nonlinearities of the catenary and tension leg mooring system, such as nonlinear stiffness of catenary and its interaction with seabed. The aerodynamics of wind turbine is modeled using blade element and momentum theory.

In Chapter 5, the developed model is used to discuss influence of floater and mooring system on dynamic response of floating wind turbine system. It is found that heave plates influence heave response by shifting resonance peak to longer period and reducing heave response in the short period region. The hydrostatic method underestimates heave response of floating system after resonance peak while the non-hydrostatic method provides good agreement with experiments. The linear model for the catenary mooring overestimates surge response in resonance region, while the linear model for the tension leg mooring agrees with nonlinear model, since the contribution of dynamic tension is very significant in catenary mooring while it is negligible for tension leg mooring. The linear model, however, underestimates the dynamic tension in both types of mooring system. The effect of wave direction on floater modes of motion is also investigated at rated and extreme states, which shows that the along wave response is nearly independent of wave direction for a symmetric floater with symmetrical mooring system. Considering the ratio of the response amplitudes for the two mooring systems, it can be observed that the two models provide comparable results in surge, sway and yaw, while heave, pitch and roll are nearly zero for tension leg mooring.

Chapter 6 investigates effect of environment loads and floater motion on tower loading using the National Renewable Energy Laboratory's 5MW- Baseline Wind Turbine. The wind and wave loads are considered separately and then together to identify their respective contribution to supporting system. Wave loads are found to be critical for tower base while wind loads govern the tower top moments. The effect of restraint of floater motions has been investigated using catenary and tension legged type mooring. In comparison with catenary mooring, the tension leg mooring is found to reduce the tower base moment by up to 50 % due to restraint of pitch motions. The effect of pitch motions is also discussed considering a simplified model that only use tower base acceleration. The comparison indicates that such a simplified model can provide reasonable prediction of tower base moment for tension leg supported floater system, but cannot reproduce the tower base moment for the floater with catenary mooring due to neglect of pitch motions in the simplified model.

Chapter 7 summarizes conclusions of this study. A fully nonlinear finite element model for dynamic response analysis of floating wind turbine system has been developed and verified. A non-hydrostatic method for restoring force is proposed that provide better agreement with experiment compared to hydrostatic method. Heave plates are found to influence heave response by changing its natural period and reducing heave response in the short period region. Considering influence of mooring system modeling, it is observed that nonlinear model are essential for realistic response prediction and only nonlinear model can provide reasonable prediction of dynamic tension. The influence of floater motion on wind turbine loading has been investigated using catenary and tension legged mooring systems. It has been identified that pitch motion of the floater is critical for tower base moments.